Jet-induced medium excitation in $\gamma$-hadron correlation

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1 Introduction

2 CoLBT-Hydro model
   • Linear Boltzmann jet transport model
   • Coupled Linear Boltzmann jet transport with 3+1D hydrodynamical model

3 Results
   • Medium modification of $\gamma$-triggered hadron yields
   • $\gamma$-hadron azimuthal correlation in RHIC energy

4 Summary and outlook
Experimental:
- The suppression of high $p_T$ hadrons
- Jet structure modification

Theoretical:
- Partonic energy loss in medium
- Collisional and radiative energy loss

$\gamma_{\text{dir}}$-$\text{h}$ correlation measurement: study the mechanism of parton energy loss.

- Direct photon produced from the Compton and annihilation subprocesses
- Direct photon trigger: direct measurement of the initial parton energy

In this talk, we focus on studying $\gamma_{\text{dir}}$-$\text{h}$ correlation using **CoLBT-Hydro model**.

*Linear Boltzmann jet transport model + 3+1D hydrodynamic model.*
LBT model (Linear Boltzmann jet transport model)

LBT model studies the jet propagation in QGP medium.
- keep track of jet shower parton and thermal recoiled parton
- take into account of back reaction and denote initial thermal partons in each scattering as "negative" partons
- consider both elastic and inelastic processes
- assume propagation partons follow a classical trajectory
- describe jet transport and propagation by a set of linear Boltzmann equations.

\[ p_1 \cdot \partial f_a(p_1) = - \int \frac{d^3p_2}{(2\pi)^32E_2} \int \frac{d^3p_3}{(2\pi)^32E_3} \int \frac{d^3p_4}{(2\pi)^32E_4} \sum_{b(c,d)} [f_a(p_1)f_b(p_2) - f_c(p_3)f_d(p_4)] \]

\[ |M_{ab\rightarrow cd}| \times S_2(s, t, u)(2\pi)^4 \delta^4(p_1 + p_2 - p_3 - p_4) + \text{radiation} \]

- linear approximation: neglect interaction between jet shower partons and recoiled partons

Hanlin Li, Fuming Liu, Guo-liang Ma, Xin-Nian Wang, Yan Zhu Phys.Rev.Lett. 106, 012301
CoLBT-Hydro model is used to simulate both the transport of jet shower partons and jet-induced medium excitation.

The source term $J^\nu$ can be expressed by:

$$J^\nu = \sum_{i=1}^{n} \frac{P^\nu_{(\text{soft})}}{d\tau} \delta^3(\vec{X} - \vec{X}_i) - \sum_{i=1}^{m} \frac{P^\nu_{(\text{neg})}}{d\tau} \delta^3(\vec{X} - \vec{X}_i)$$

soft: partons with $p.u < E_{\text{cut}}$

neg: "negative" partons from back reaction

- **Assumption**: Instantaneous local thermalization of deposited energy and momentum
Initial condition and hadronization

**Initial condition:**
- hydro initial condition
- initial production positions of jet partons
- energy-momentum of jet partons different in each event

**Hadronization:**
- LBT part:
  1. Record all hard partons' information at $T < T_c$
  2. Put these information into recombination model from Texas A-M group
     
     Kyong Chol Han, Rainer J. Fries, Che Ming Ko J.Phys.Conf.Ser. 420 (2013) 012044

- Hydro part: Cooper-Frye formula
Jet propagation and jet-induced medium excitation

Jet propagation in hot medium at $\tau=0.4\, fm$
Jet propagation in hot medium at $\tau=0.8\text{fm}$

Jet propagation and jet-induced medium excitation

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Jet propagation and jet-induced medium excitation

Jet propagation in hot medium at $\tau=1.2\, fm$
Jet propagation and jet-induced medium excitation

Jet propagation in hot medium at $\tau = 1.6 \, fm$
Jet propagation and jet-induced medium excitation

Jet propagation in hot medium at $\tau=2.0\text{fm}$
Jet propagation and jet-induced medium excitation

Jet propagation in hot medium at $\tau = 2.4 \text{fm}$

![COLBT-HYDRO](xy-plane at $\eta_z = 0$)

![COLBT-HYDRO MINUS BACKGROUND](xy-plane at $\eta_z = 0$)
Jet propagation and jet-induced medium excitation

Jet propagation in hot medium at $\tau = 2.8 fm$

Jet-induced medium excitation in $\gamma$-hadron correlation
Jet propagation and jet-induced medium excitation

Jet propagation in hot medium at $\tau = 3.2\, fm$

![Jet propagation in hot medium at $\tau = 3.2\, fm$](image)
Jet propagation and jet-induced medium excitation

Jet propagation in hot medium at $\tau=3.6\,fm$

[Diagram showing energy density in COLBT-HYDRO and COLBT-HYDRO MINUS BACKGROUND]
Jet propagation and jet-induced medium excitation

Jet propagation in hot medium at $\tau=4.0\,fm$

![COLBT-HYDRO](image1)

![COLBT-HYDRO MINUS BACKGROUND](image2)
Jet propagation and jet-induced medium excitation

Jet propagation in hot medium at $\tau=4.4\,fm$

Jet propagation in hot medium at $\tau=4.4\,fm$
Jet propagation and jet-induced medium excitation

Jet propagation in hot medium at $\tau=4.8\,fm$
Jet propagation and jet-induced medium excitation

Jet propagation in hot medium at $\tau=5.2\,fm$
Jet propagation and jet-induced medium excitation

Jet propagation in hot medium at $\tau = 5.6 \text{fm}$

![Graph showing jet propagation in hot medium at $\tau = 5.6 \text{fm}$](image)

- **COLBT-HYDRO**
- **COLBT-HYDRO MINUS BACKGROUND**

**xy-plane at $\eta_c = 0$**

**energy density**

- 0.00
- 0.25
- 0.50
- 0.75
- 1.00
- 1.25
- 1.50
- 1.75
- 2.00
- 2.25

- $-0.24$
- $-0.16$
- $-0.08$
- 0.00
- 0.08
- 0.16
- 0.24
- 0.32
- 0.40

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Jet propagation and jet-induced medium excitation

Jet propagation in hot medium at $\tau=6.0\,fm$

Jet-induced medium excitation in $\gamma$-hadron correlation
Jet propagation and jet-induced medium excitation

Jet propagation in hot medium at $\tau=6.4 fm$
Jet propagation and jet-induced medium excitation

Jet propagation in hot medium at $\tau=6.8\,fm$

Jet propagation in hot medium at $\tau=6.8\,fm$
Jet propagation in hot medium at $\tau = 7.2\, fm$
Jet propagation and jet-induced medium excitation

Jet propagation in hot medium at $\tau = 7.6\, fm$

![COLBT-HYDRO](image1)

![COLBT-HYDRO MINUS BACKGROUND](image2)

xy-plane at $\eta_c = 0$
Jet propagation and jet-induced medium excitation

Jet propagation in hot medium at $\tau=8.0\,fm$
γ_{dir}-hadron correlation from CoLBT-Hydro model

γ_{dir}-hadron correlation in A+A: two contributions with CoLBT-Hydro model

LBT part: Hadron spectrum from hard partons remained at \( T < T_C \)

Hydro part: Hadron spectrum from jet-induce medium excitation

\[
\frac{dN^{\text{hydro}}}{d\phi p_T dp_T dY} = \frac{dN^{\text{hydro}}}{d\phi p_T dp_T dY_{\text{jet}}} - \frac{dN^{\text{hydro}}}{d\phi p_T dp_T dY_{\text{nojet}}}
\]  

(2)

with the same hydro initial conditions in both cases

Average all events with different γ-jet initial production positions and propagation direction

γ_{dir}-hadron correlation in p+p: Input initial jet partons information into recombination model
Medium modification of $\gamma$-triggered hadron yields in RHIC energy

$\gamma$-triggered fragmentation function

medium modification of $D(z_T)$

\[
\gamma \rightarrow \text{hadron yields}
\]

\[
\Delta \phi = |\phi| < 1.4; |\eta| < 1.0
\]

\[
D(z_T) \text{: per-trigger charged-hadron yields}
\]

\[
I_{AA} = \frac{D(z_T)}{D(z_T)_{pp}}
\]

- Suppression in high $z_T$ and enhancement in low $z_T$
- The energy loss of hard partons result in the enhancement of soft particles production
Medium modification of $\gamma$-triggered hadron yields in RHIC energy

\[ \xi = \ln \frac{1}{z_T} \quad z_T \equiv \frac{p_T^{assoc}}{p_T^{trig}} \]

with $p_T^{\gamma}$ range increasing:

- Transition point from suppression to relative enhancement shifts to high $\xi$
- Transition point corresponds to the fixed $p_{T,assoc}$ range

We can get that enhancement at small $\xi$ due to medium excitation.
$I_{AA}$ for different away-side integration range

Reduce the integration range

1. the enhancement at high $\xi$ reduce
2. the point with $I_{AA}=1$ shifts to high $\xi$

The medium enhances production of soft particles in parton fragmentation, relative to pp, preferentially at large angles
γ-hadron azimuthal correlation in RHIC energy

- Large suppression at high pt range
- Significant enhancement of hadron yields at low pt range
- A broadened peak at low pt range
- Smaller hadron yield in near side at low pt range

$AuAu200\,GeV\,0 \sim 12\%$

$12 < P_T^\gamma < 20\,GeV/c$

$|\Delta \phi - \pi| < 1.4; |\eta| < 1.0$

$\sigma$: Gaussian width
negative distribution at gamma direction is due to the effect of diffusion wake caused by the deposition of energy-momentum into the medium

**conclusion**

- the lost energy-momentum from high-pt jets along the jet direction are transformed into low-pt hadrons at large angle
- the redistribution of lost energy into the medium causes smaller hadron yield in near side at low pt range
• We use CoLBT-Hydro model to simulate both the transport of jet shower partons and jet-induced medium excitation.

• The study of medium modification of jet fragmentation indicates soft particles production enhances at low $\xi$ due to the energy loss of jet partons traversing the medium.

• Transition from suppression to relative enhancement occurs at a fixed $p_T$ range in the RHIC energy.

• The study of the $\gamma$-hadron azimuthal correlation make further illustration about the redistribution of lost energy into the medium.